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# Material type and roughness influence structure of intertidal communities on coastal defences

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## Abstract

On a global scale, urbanisation has resulted in substantial proportions of the coast being replaced by artificial structures such as marinas, breakwaters or seawalls. There is broad consensus that coastal defence structures are poor surrogates of the natural habitats they replace. Here we investigate the effect of the type and roughness of materials used for the construction of artificial structures on the biota by comparing abundances and distribution of key intertidal taxa between natural shores and coastal defences. Lower abundance of gastropods and barnacles were found on artificial coastal defence structures (regardless of the material type). At small–spatial scales, there was a significant effect of roughness which increased the abundances of key taxa. Results suggest that choice of materials used for the construction of coastal defence structures *per se* has little effect on community structure, but that enhanced roughness could make coastal defences better surrogates of natural habitats by supporting assemblages that are more similar to those found on natural shores.

**Keywords**: artificial structures, intertidal assemblages, marine biodiversity, urbanisation, macroalgae

## Introduction

The extent of natural coastal habitats converted for urban use, including the construction of coastal defence structures such as seawalls, breakwaters or groynes, is increasing globally (Goodsell 2009; Firth *et al*. 2013). This trend is likely to continue, given predictions for sea level rise and increased storminess (Thompson *et al*. 2002; Wong *et al*. 2014). There is thus a clear interest in understanding the environmental consequences of these artificial habitats (Moschella *et al*. 2005), with several studies highlighting the importance of understanding the underlying ecological processes (Moreira *et al*. 2006; Munari 2013) when planning developments along shores (Chapman & Bulleri 2003).

Construction of artificial structures provides additional hard substrata for epibenthic organisms. These structures, however, can have a strong effect on the structure and functioning of flora and fauna assemblages in adjacent hard- or soft-bottom habitats (e.g. Martin *et al*. 2005; Martins *et al*. 2009; Bertasi *et al*. 2007). Moreover, although epibiotic communities on artificial structures can be qualitatively similar to those on natural rocky shores, differences in the diversity, abundance, behaviour and/or phenology of epibiota on breakwaters, seawalls or groynes have been reported by many authors (e.g. Chapman 2003; Chapman & Bulleri 2003; Bulleri *et al*. 2004; Moschella *et al*. 2005; Moreira 2006; Moreira *et al*. 2006; Martins *et al*. 2009; Firth *et al*. 2013). Collectively, these studies suggest that artificial structures cannot generally be considered surrogates of the natural habitats they replace.

Some studies consider that artificial structures built with locally quarried materials are likely to have minimal effect on intertidal assemblages, and therefore predict that the

epibiotic communities on those structures would be similar to those colonizing nearby natural rocky habitats (see Thompson *et al*. 2002; Branch *et al*. 2008). However, there is evidence that this is not always true and differences have been found between assemblages on natural habitats and artificial structures made of locally quarried rock (see Bulleri & Chapman 2010, for review). Moreover, current literature on the effects of coastal urbanisation includes ambiguous results, revealing both positive and negative effects on the maintenance of local populations. For instance, the outcomes of investigations on the effects of coastal urbanisation on the distribution of limpets have been variable. Some authors (Moreira *et al*. 2006; Díaz–Agras *et al*. 2010) found no differences in the abundance or frequency of occurrence of limpets inhabiting artificial substrata and rocky shores, while other authors reported greater numbers of limpets on either natural (e.g. Bulleri & Chapman 2004; Bulleri *et al*. 2004) or artificial structures (Guerra–García *et al*. 2004).

Modification of artificial structures to make them better surrogates of natural habitats is a form of mitigation that is receiving increasing attention (Moreira *et al*. 2007; Chapman and Blockey 2009; Martins *et al*. 2010; Firth *et al*. 2013). Some attempts to reduce their ecological impacts have been addressed by adding elements (e.g. wetland vegetation) or features of habitat (e.g. rock-pools) that are absent from urban structures (Zedler & Leach 1998; Bulleri & Chapman 2010). Natural rocky shores differ from artificial structures in a number of important features (Chapman and Blockey 2009; Firth *et al*. 2013) namely differences in material composition and structural roughness, and there is now a substantial body of work highlighting the important role of substratum heterogeneity in structuring intertidal communities (Thompson *et al*. 1996; Pinn *et al*. 2008; Griffin *et al*. 2009; Skov *et*

82 *al*. 2011; Gartner *et al*. 2013). Artificial structures generally fail to provide the array and
83 diversity of habitat heterogeneity found on most natural shores (Chapman 2006; Firth *et al*.
84 2013; Browne & Chapman 2014). For instance, seawalls generally lack microhabitats such
85 as rock pools that retain water during low tide allowing the establishment specialist species
86 (Chapman & Blockley 2009; Firth *et al*. 2013; Browne & Chapman 2014). Likewise,
87 seawalls or groynes have steep inclinations, which reduce the areal extent of the intertidal
88 zone compared to the generally gentler slope of natural habitats (Moreira *et al*. 2007;
89 Bulleri & Chapman 2010). Therefore, we hypothesize that artificial structures with rougher
90 surfaces, i.e., more similar to natural habitats, will benefit intertidal species, at least those
91 small-sized which can easily find refuge from the harsh intertidal conditions.

92 The ecological impacts of coastal infrastructure in shallow coastal waters may vary
93 accordingly with the nature of the surrounding habitat (Bulleri & Chapman 2010). Most of
94 the research to date has considered coastal defences that lie behind soft sedimentary
95 shorelines that are at risk form erosion (Gacia *et al*. 2007), thus providing additional hard
96 surface for colonization by benthic organisms where it was previously absent (Chapman &
97 Bulleri 2003; Moschella *et al*. 2005). This study was conducted in the Azores, an oceanic
98 archipelago where volcanic rubble and steep cliffs constitute the most common marine
99 habitats. In the Azores, most artificial structures are used to protect nearby towns from high
100 sea levels during winter storms. In contrast to many other locations worldwide, coastal
101 defences in the Azores are typically built on top of former natural stretches of rocky coasts,
102 thus showing similarities in physical nature (i.e., hard substrate) to adjacent natural
103 environments. Therefore, unlike areas where artificial structures are deployed on soft-
104 bottom areas, we hypothesize that assemblages on most of the Azorean artificial structures

105 will be of similar composition to those found on adjacent natural environments. However,
106 given the well known effect of substratum type in structuring intertidal assemblages (e.g.
107 Connell & Glasby 1999; Glasby 1999), the first objective in this study was exactly to
108 compare patterns of distribution and abundance of intertidal organisms on natural rocky
109 shores with that of coastal defence structures (boulders and blocks) made of either basalt
110 (locally quarried rock) or concrete (a non–natural substratum, and probably the most
111 common material used in coastal urbanisation). We are interested in testing if using rocks
112 that were locally quarried would somehow minimise the impacts of coastal urbanisation. In
113 addition to this, we also investigated how natural small-scale variability in substratum
114 topography (within artificial structures made of basalt) influences the structure of intertidal
115 assemblages. We predict that areas of the substratum with rougher topography will support
116 assemblages that differ from those found in areas of the substratum with smoother
117 topography.

118 This information will help to understand the effects of hard defence structures, and may be
119 potentially provide information that can be used to mitigate the ecological impacts of
120 coastal urbanisation (e.g. Martin *et al*. 2005; Moschella *et al*. 2005; Martins *et al*. 2010).

121 **Material and Methods**

122 The study was conducted on São Miguel Island (Azores, Fig. 1), where maximum tidal
123 range is approximately 2 m and the coast is exposed to medium to high levels of wave
124 action. In general, three zones can be recognized in the São Miguel Island rocky intertidal,
125 following classical zonation schemes (Stephenson & Stephenson 1972): the low–shore is
126 characterized by a covering of coarsely branched, coralline and turf–forming species of

127 macroalgae; the mid–shore is dominated by the barnacle *Chthamalus stellatus*, whereas the
128 gastropod littorinids *Tectarius striatus* and *Melarhaphe neritoides* usually inhabit in the
129 upper–shore (Martins *et al*. 2008b).

130 To characterize the intertidal assemblage community composition and abundance, sampling
131 was carried out on natural rocky shores of basaltic nature (hereafter referred to as Natural
132 shore), and artificial coastal defence structures built of either basalt (hereafter Basalt
133 artificial structures) or concrete (hereafter Concrete artificial structures) located along the
134 coastline of São Miguel (176 km perimeter, length 65 km, width 8–15 km) (Fig. 1). Only
135 the seaward sides of natural and artificial habitats were sampled to standardize for wave
136 exposure. Five locations representative of the three habitat types (Natural shore, Basalt
137 artificial structures and Concrete artificial structures) were randomly selected (Fig. 1). All
138 locations were separated by tens of kilometers and similarly exposed to incoming oceanic
139 swell. Within each location, five replicate quadrats (25x25 cm) were randomly placed at
140 least 2 m apart on emergent substrata at low–, mid– and upper–shore levels, visually
141 determined by the presence of macroalgae, barnacles and littorinid respectively. The
142 assemblage structure was hence assessed at each level. Percentage cover of sessile
143 organisms (e.g. macroalgae, barnacles) and bare rock (a measure of unoccupied space)
144 were obtained following the methodology described in Dethier *et al*. (1993), in which the
145 abundance of organisms within each of the 25 5x5 cm sub–quadrats (that add up a sampling
146 quadrat) was assigned a score ranging between 0 (absent) and 4 (100% cover of the sub–
147 quadrat). Total percentage cover is then estimated by summing the scores of all sub–
148 quadrats (see Dethier *et al*. 1993 for further details). Macroalgae were identified and
149 grouped into distinct morpho–functional groups (FGs), based on species's morphology and

150 the way they compete for resources (Steneck & Dethier 1994; Arenas *et al*. 2006; Veiga *et*
151 *al*. 2013). The selected FGs were: Ephemerals (considering first colonizers, including
152 diatomaceous biofilms, microalgae and filamentous algae such as *Chaetomorpha*,
153 *Cladophora*), Foliose (e.g. *Pophyra*, *Ulva rigida*), Coarsely branched (e.g. *Caulacanthus*
154 *ustulatus*), Coenocytic (*Codium adhaerens*), Articulated calcareous (e.g. *Corallina*
155 *elongata*), Leathery (e.g. *Fucus spiralis*), Calcified crustose (e.g. *Lithophyllum*), and Non–
156 calcified crustose (e.g. *Nemoderma*). Taxa present within quadrats but not reaching a score
157 of 1 were given a nominal value of 0.5%. Motile invertebrates were identified up to species
158 level, counted and expressed as number of individuals per quadrat. All surveys were made
159 between the 24$^{th}$ June and 4$^{th}$ August 2013, during low–water spring tides.

160 A complementary small-scale study investigated the role of substratum roughness in
161 determining patterns of species distribution on coastal defence structures by comparing the
162 abundance of organisms in blocks with smooth and rough surfaces visually selected *a*
163 *priori* on a basalt seawall at two sites selected 10's of meters apart. Five replicate plots on
164 smooth *vs*. rough blocks were sampled. In this case, only mid– and upper–shore was
165 sampled in this survey, since low–shore roughness was hidden by dense macroalgal
166 dominance. A pin–microrelief method (Vázquez *et al*. 2009) was adapted to measure
167 substratum random roughness (RR) in the sampled plots. Differences in substratum surface
168 height were recorded in 15 cm transects with spacing between readings of 2.5 mm, and RR
169 index was calculated as the standard error among heights (Allmaras *et al*. 1966). This
170 survey was made between August 12$^{th}$ and September 12$^{th}$ 2014, during low–water spring
171 tides. Sampling of the biota was done as described above.

172 Data analysis

173 Multivariate analysis.

174 Differences in the structure of assemblages were investigated for each tidal height using a
175 two–way permutational analysis of variance (PERMANOVA) with habitat (Ha, fixed, with
176 three levels: Natural shores, Basalt artificial structures and Concrete artificial structures)
177 and location (Lo, random, nested in habitat, with five levels) as factors. PERMANOVA
178 analyses were run on Bray Curtis similarity matrix of both untransformed and presence–
179 absence transformed complete epibenthic assemblage (i.e. including percentage cover of
180 macroalgae/barnacles and abundance of gastropods). Pair-wise tests were used to compare
181 the effects within significant factors.

182 Univariate analysis.

183 The numbers of macroalgal FGs as well as the relative abundance of taxa were compared
184 among habitats following the same procedure as described before but using, in this case,
185 traditional analysis of variance. Prior to analyses, Cochran's test was used to detect
186 heterogeneity of variances and data were transformed where appropriate (Underwood
187 1997). When homogeneity of data was not achieved after transformation, analyses were run
188 on the untransformed data but using a more conservative significance level ($P < 0.01$)
189 (Underwood 1997).

190 The role of roughness in determining small–scale patterns of species distribution in hard–
191 defence structures, namely the abundance of gastropods and the percentage cover of
192 barnacles, was also investigated using an approach similar to that described above, but
193 including roughness (Ro, fixed, two levels: Smooth and Rough) and site (Si, random, two
194 levels) as factors.

195 Multivariate analyses were run using PRIMER 6 statistical package with the
196 PERMANOVA+ add–on (PRIMER–E, Plymouth Marine Laboratory, UK), whereas
197 univariate analysis were run using GMAV5 (University of Sydney).

198 **Results**

199 Multivariate analysis.

200 Assemblage structure (both on the untrasformed, Table 1a, and presence–absence data,
201 Table 1b) did not differ significantly among habitats (i.e., Natural shore, Concrete and
202 Basalt artificial structures) on the lower–shore. On the mid–shore, assemblage structure
203 differed significantly between Natural and Basalt when considering abundance data (Table
204 1a), but not when considering only compositional data (Table 1b). Significant differences
205 on the assemblage structure were detected between Natural shores and both artificial
206 habitats (Concrete and Basalt artificial structures) on the upper–shore, when considering
207 abundance (Table 1a) but not presence-absence (Table 1b) data.

208 Univariate analysis.

209 The numbers of macroalgal FGs were generally similar among habitats at all tidal levels,
210 although differences were found among locations ($P < 0.001$, Table 2, Fig. 2).

211 Al low-shore level, the abundance of macroalgal FG showed no differences among habitats,
212 although differences were found among locations ($P < 0.001$, Table 3, Fig. 3).

213 At mid-shore level, only coarsely branched algae were significantly more abundant on
214 Natural shores than on artificial reefs (means of 6.0% on Natural *vs*. 0.8% on Basalt and
215 0.7% on Concrete artificial structures; Table 3, Fig. 3). The abundance of the remaining

functional groups (coenocytic, foliose, articulated calcareous, leathery and calcified and non–calcified crusts) did not vary significantly among natural shores and basalt and concrete artificial habitats, although differences were always found among locations (Table 3, Fig. 3). The number of both M. *neritoides* and *T. striatus* was significantly greater on natural shores than in artificial structures (Table 4, Fig. 4). Mean numbers of littorinids from 0.08 to 1.6 ind. 0.06 $m^{-2}$ were observed on coastal defences, while densities between 10.9 and 12.8 ind. 0.06 $m^{-2}$ were observed on natural shores (Fig. 4). The abundance of *Patella* spp. did not significantly differ between habitats (Fig. 4, Table 4), while the cover of *C. stellatus,* was significantly greater on Natural shores compared to Basalt artificial structures (28.3 *vs*. 5.5 % respectively, Fig. 4, Table 4).

Regarding the upper-shore, significant differences were detected among habitats when considering the percent cover of ephemerals, more abundant on Basalt artificial structures (0.14%) than in Concrete artificial structures (0.04%, Table 3, Fig. 3). Articulated calcareous and calcified crusts showed differences among locations ($P < 0.001$, Table 3, Fig. 3), but not among habitats. The abundance of *T. striatus* significantly differed between habitats (Fig. 4, Table 4), with numbers of 11.8 ind. 0.06 $m^{-2}$ in natural shores and 1.5 in artificial structures. The numbers of the remaining faunal species were similar among habitats, although differences were found among locations ($P < 0.05$, Table 4, Fig. 4).

Small-scale effect of substratum roughness.

There were significant differences in substratum roughness between the *a priori* selected smooth *vs*. rough surfaces, with values of 0.18 ± 0.02 mm (mean ± SE, $n = 20$) and 0.05 ±

237 0.01 respectively (ANOVA, Mid–shore: $F(1,17)$ (pooled) = 16.13, $P < 0.001$; Upper–shore:
238 $F(1,17)$ (pooled) = 16.22, $P < 0.001$).

239 At mid-shore level, significant differences were found in the mean abundance of *M.*
240 *neritoides* and *C. stellatus* between rough and smooth blocks although these effects were
241 site-dependent. *M. neritoides* was significantly more abundant on rough blocks (mean
242 values of 10.4 in rough *vs.* 0.10 ind. 0.06 $m^{-2}$ in smooth surfaces) at site 1, while *C.*
243 *stellatus* was significantly more abundant on smooth blocks on both sites (mean cover of
244 39.4% in smooth *vs*. 6.8% in rough blocks; Fig. 5, Table 5). The littorinid *T. striatus* was
245 significantly more abundant on rough surfaces at both the mid– and the upper–shore (mean
246 number of 12.3 in rough *vs*. 0.2 ind. 0.06 $m^{-2}$ in smooth surfaces on mid– and 16.7 *vs*. 1.0
247 ind. 0.06 $m^{-2}$ on upper–shore levels; Fig 5, Table 5).

248 **Discussion**

249 As we hypothesized, qualitatively similar assemblages of animals and plants were found on
250 both the coastal defence structures and natural habitats. There were, however, relevant
251 effects of urbanisation on the abundance of some intertidal organisms. For instance, the two
252 littorinid species and the cirripid barnacle were substantially (and significantly) less
253 abundant on the artificial structures. Moreover, this effect was generally similar on defence
254 structures made of either concrete or basalt suggesting that they were not directly
255 influenced by the material type of the substratum *per se*. Results from the small–scale study
256 showed that these species were highly influenced by small–scale variation in roughness.
257 The lower abundance of littorinids found on artificial structures may thus be related to the
258 general lack of microtopographic features that are important as habitat for these molluscs.

This is in accordance with the wider literature showing that littorinids generally tend to aggregate around small–scale features of the substratum (Chapman 1995; Jones & Boulding 1999; Silva *et al*. 2014). Both the physical characteristics of the habitats (roughness; e.g. Gray and Hodgson 2004) and also the presence of *C. stellatus*, could provide refuges for this fauna. As observed by other authors (Silva *et al*. 2014), small gastropods were observed inhabiting the tests of dead barnacles, acting therefore as biogenic microhabitats (Aguilera *et al*. 2014), altering the complexity of the substratum and providing shelter and protection from physiological stress to intertidal organisms (Underwood *et al*. 1983; Jernakoff 1985). Roughness has been also considered an important variable on barnacle settlement (e.g. Chabot & Bourget 1988; Skinner & Coutinho 2005). Barnacles had lower abundance on artificial structures (as observed e.g. by Aguilera *et al*. 2014), but in our case, within the artificial structures the effect of roughness contrasted that found for littorinids (i.e., lower abundance on smooth surfaces). Although we did not expect biotic or abiotic factors to differ between sites within the artificial shore, e.g. chemical cues generated by barnacle adults could be influencing our results, since barnacles are known to respond positively to the presence of conspecifics (Skinner & Coutinho 2005), and we could no separate such effects from those related to roughness.

Due to their key role in intertidal assemblages, changes in limpet abundance among habitats may indirectly influence the distribution of other organisms (Hawkins *et al*. 1992). In the present study, and in contrasts with Bulleri & Chapman (2004) or Bulleri *et al*. (2004), although natural habitats supported greater densities of limpets than basalt at low–shore levels, no differences were found on the mid–shore, where limpets are usually more abundant (Martins *et al*. 2010). In this and other systems (e.g. Oliva & Castilla 1986,

Branch & Moreno 1994, Moreno 2001) , substantial harvesting of limpets, a traditionally important source of income for many families (Ferraz *et al*. 2001; Martins *et al*. 2008a) may have masked natural patterns of distribution.

Generally, no differences were found in the number of macroalgal functional groups among habitats. However, a lower number of functional groups tended to be found on the upper–shore on natural shores. These macroalgae vary in consistent ways along physical gradients, including, e.g., wave exposure and desiccation (Menge 2000). Wave splash operates vertically, allowing organisms to extend upwards (Ballesteros & Romero 1988; Hobday 1995). In the case of artificial structures, the steep slope may break waves violently against the artificial structures (Allsop *et al*. 2005), encompassing long–term exposure to waves (wetting gradient, Chappuis *et al*. 2014). This could directly affect the vertical distribution of some functional groups, such as calcified and non–calcified crustose algae. Only on the mid– and upper–shore was the epibenthic assemblage composition of coastal defences different from natural habitats. Unlike results from Bulleri & Chapman (2004) who found compositional differences (differences in species identities) in assemblages on seawalls and adjacent rocky shores, we did not find such compositional differences. In our study system, differences found between natural shores and artificial structures were largely restricted to changes in species abundances (not identity).

## Conclusion

Information about patterns of distribution of species in natural and artificial habitats is essential in order to understand the ecological impacts of coastal infrastructures (Bulleri & Chapman 2010). Some studies have suggest that artificial structures provide habitat for

304 epibiotic communities that are qualitatively similar to those found inhabiting nearby natural
305 reefs (e.g. Branch *et al*. 2008) but quantitative studies (e.g. Moschella *et al*. 2005; Firth *et*
306 *al*. 2014), have shown artificial structures have significantly lower abundance of
307 gastropods, barnacles and coarsely branched algae, indicating some lack of similarity with
308 natural rocky shores. Our study indicates that roughness, rather than substratum type *per se*,
309 can play a key role in determining the distribution of barnacles and littorinids. Our results
310 indicate that selection of materials with rougher surfaces (i.e. enhanced roughness) when
311 building hard–defence structures may be an effective way to make them more similar to
312 natural substrata, enabling them to support taxa abundance more similar to those found on
313 natural shores.

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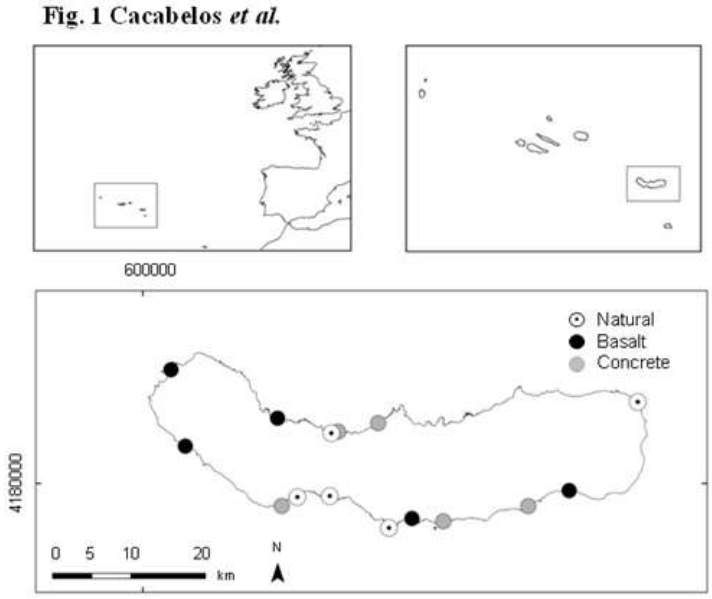
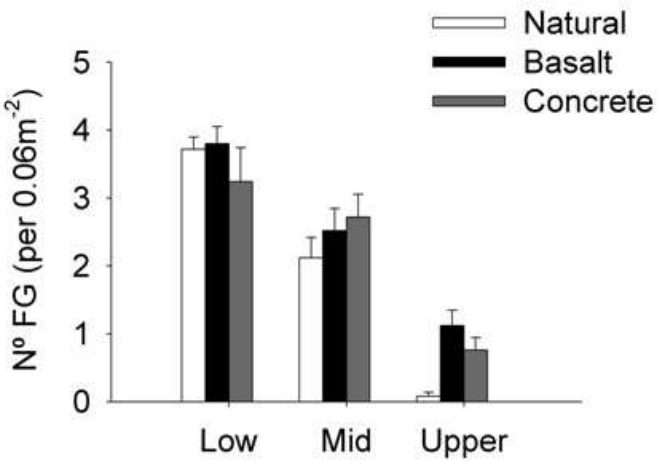
## Figures

**Fig. 1** Sampling locations on Natural shores and Basalt and Concrete artificial structures around São Miguel (Azores).



543 **Fig. 2** Macroalgal morpho–functional groups (mean number + SE, $n$ = 25) on Natural
544 shores and Basalt and Concrete artificial structures at different intertidal levels.

**Fig. 2. Cacabelos *et al.***

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559 **Fig. 3** Covers of macroalgal morpho–functional groups (mean + SE, $n$ = 25) associated
560 with Natural shores and Basalt and Concrete artificial structures at different intertidal levels
561 (E, Ephemeral Algae; CB, Coarsely branched; Co, Coenocytic; F, Foliose; AC, Articulated
562 calcareous; L, Leathery; CC, Calcified crustose, NCC, Non–calcified crustose).

**Fig. 3. Cacabelos *et al.***

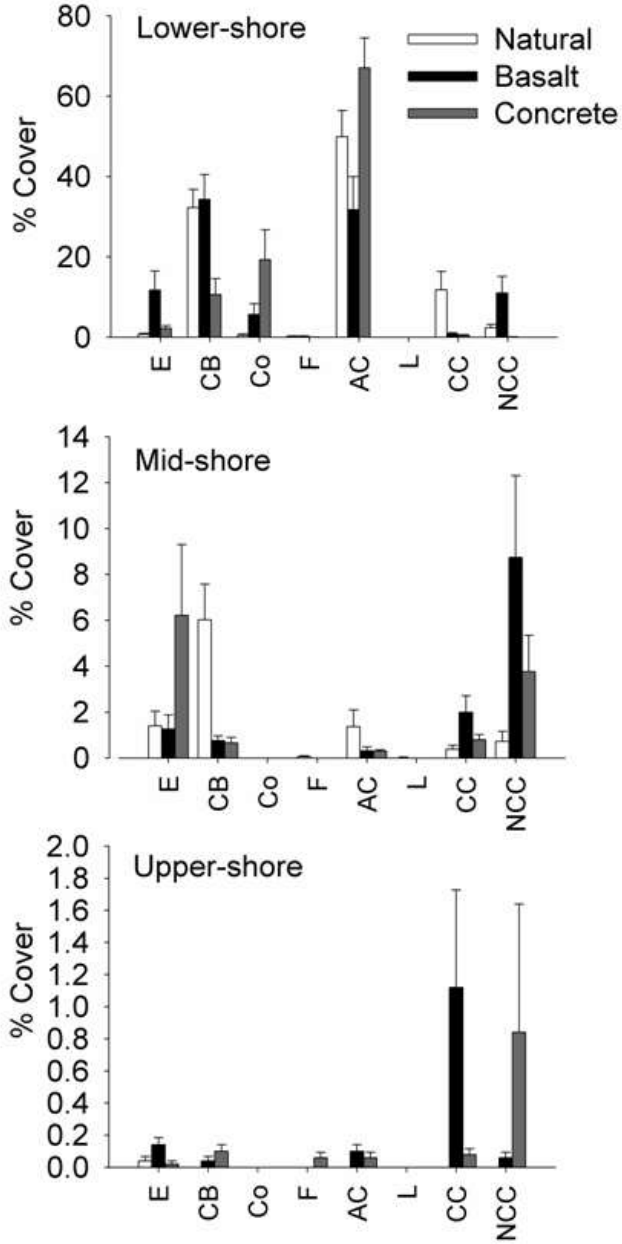


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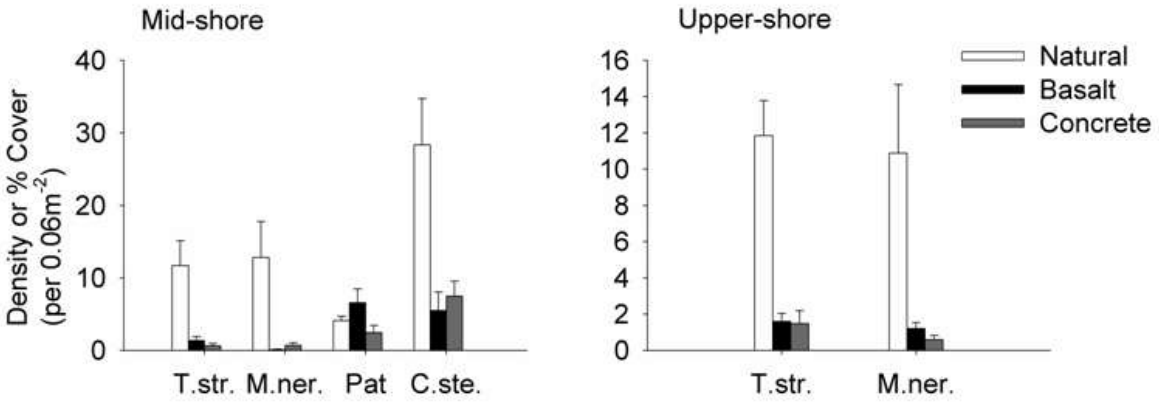
**Fig. 4** Gastropod (mean number + SE, $n$ = 25) and barnacle (percent cover + SE) abundance associated with Natural shores and Basalt and Concrete artificial structures at mid– and upper–shore (molluscs: T.str, *T. striatus*; M.ner., *M. neritoides*; Pat, *Patella* spp.; barnacle *C. stellatus*, C.ste.).

**Fig. 4. Cacabelos *et al.***



584 **Fig. 5** Gastropod (mean number + SE, *n* = 10) and barnacle (percent cover + SE)
585 abundance associated with rough and smooth surfaces at mid– and upper–shore (molluscs:
586 T.str, *T. striatus*; M.ner., *M. neritoides*; Pat, *Patella* spp.; barnacle *C. stellatus*, C.ste.).

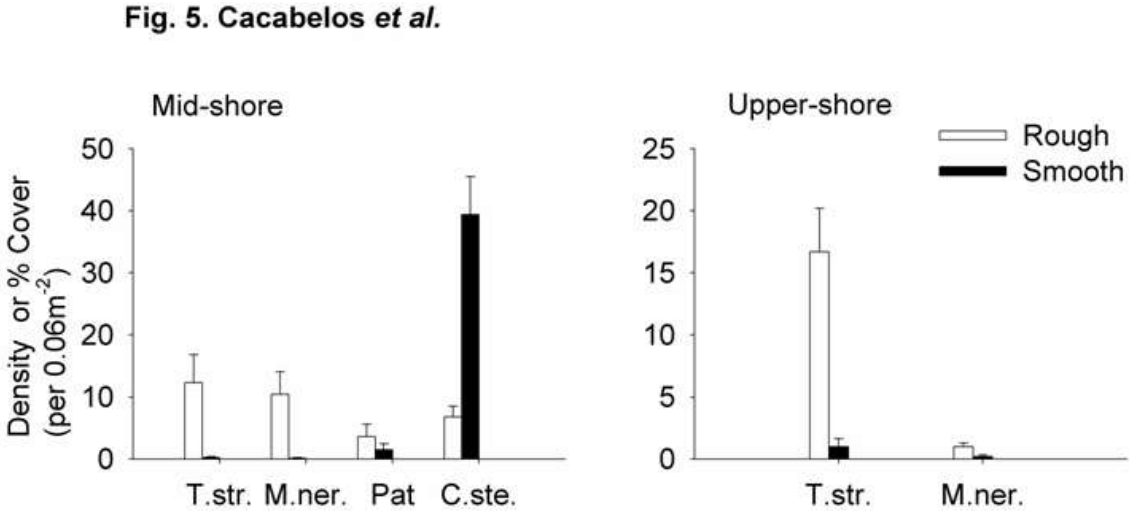



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**Table 1** Two-way PERMANOVA comparing a) untransformed and b) presence/absence transformed assemblage structure data (including numbers of gastropods and percentage cover of macroalgal functional groups and *C. stellatus*) among habitats (N Natural shore, B Basalt artificial structure, C Concrete artificial structure) and locations (five per habitat, see in Fig. 1) at different intertidal levels.*** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$.

| | | | Low-shore | | Mid-shore | | Upper-shore | |
|---|---|---|---|---|---|---|---|---|
| | Source | df | MS | *Pseudo-F* | MS | *Pseudo-F* | MS | *Pseudo-F* |
| a) | Habitat | 2 | 13146.0 | 1.59 | 13478.0 | 1.74* | 21666.0 | 4.15** |
| | Location(Habitat) | 12 | 8291.0 | 12.47*** | 7730.1 | 4.03*** | 5218.8 | 4.62*** |
| | Residual | 60 | 665.2 | | 1917.8 | | 1130.4 | |
| | Total | 74 | | | | | | |
| | Pair-wise comparisons | | | | | N diff. B* | | N diff. B**<br>N diff. C** |
| b) | Habitat | 2 | 9033.2 | 1.70 | 9687.7 | 1.77 | 8696.0 | 1.92 |
| | Location(Habitat) | 12 | 5321.2 | 6.74*** | 5480.6 | 5.25*** | 4525.9 | 4.95*** |
| | Residual | 60 | 789.9 | | 1044.4 | | 913.9 | |
| | Total | 74 | | | | | | |

620 **Table 2** Two-way ANOVA comparing the numbers of macroalgal morpho-functional
621 groups among habitats (Natural shore, Basalt artificial structure, Concrete artificial
622 structure) and locations at different intertidal levels.*** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$.

| | | Low-shore | | Mid-shore | | Upper-shore | |
|---|---|---|---|---|---|---|---|
| Source | df | MS | *F* | MS | *F* | MS | *F* |
| Habitat | 2 | 2.29 | 0.49 | 0.03 | 0.07 | 0.90 | 3.25 |
| Location(Habitat) | 12 | 4.63 | 4.96*** | 0.37 | 4.24*** | 0.28 | 5.16*** |
| Residual | 60 | 0.93 | | | | 0.05 | |
| Total | 74 | | | | | | |
| Cochran's test | | ns, 0.1786 | | ns, 0.2303 | | ns, 0.232 | |
| Transformation | | None | | X^0.1 | | Sqrt(X+1) | |

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641 **Table 3** Two-way ANOVA comparing the cover of macroalgal morpho-functional groups
642 among Habitats (Natural shores N, Basalt artificial structure B and Concrete artificial
643 structure C) at different intertidal levels. E, Ephemerals; CB, Coarsely branched; Co,
644 Coenocytic; F, Foliose; AC, Articulated calcareous; L, Leathery; CC, Calcified crustose,
645 NCC, Non-calcified crustose.*** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$.Natural (N).

| | | | Low-shore | | Mid-shore | | Upper-shore | |
|---|---|---|---|---|---|---|---|---|
| | | df | MS | *F* | MS | *F* | MS | *F* |
| | Habitat | 2 | 0.56 | 0.50 | 0.39 | 0.45 | 0.10 | 4.77* |
| | Location(Habitat) | 12 | 1.12 | 7.03*** | 0.85 | 4.04*** | 0.02 | 0.76 |
| | Residual | 60 | 0.16 | | 0.19 | | 0.03 | |
| | Total | 74 | | | | | | |
| | Cochran's test | | ns, 0.1856 | | ns, 0.1425 | | ns, 0.1765 | |
| E | Transformation | | X^0.1 | | X^0.1 | | None | |
| | Pair-wise comparisons | | | | | | | B diff. C* |
| | Habitat | 2 | 4320.10 | 2.93 | 8.11 | 7.82** | 0.06 | 2.11 |
| | Location(Habitat) | 12 | 1473.90 | 3.27*** | 1.03 | 2.40* | 0.03 | 1.64 |
| | Residual | 60 | 450.28 | | | | 0.02 | |
| | Total | 74 | | | | | | |
| | Cochran's test | | ns, 0.2037 | | ns, 0.2391 | | $P < 0.05$, 0.2727 | |
| CB | Transformation | | None | | Ln(X+1) | | None | |
| | Pair-wise comparisons | | | | N diff. B*<br>N diff. C* | | | |
| | Habitat | 2 | 2380.3 | 0.84 | | | | |
| | Location(Habitat) | 12 | 2846.7 | 44.67*** | | | | |
| | Residual | 60 | 63.7 | | | | | |
| | Total | 74 | | | | | | |
| | Cochran's test | | $P < 0.01$, 0.5898 | | | | | |
| Co | Transformation | | None | | | | | |
| | Habitat | 2 | 0.24 | 0.40 | 0.03 | 1 | | |
| | Location(Habitat) | 12 | 0.61 | 4.45*** | 0.03 | 6** | | |
| | Residual | 60 | 0.14 | | 0.01 | | | |
| | Total | 74 | | | | | | |
| | Cochran's test | | $P < 0.01$, 0.6341 | | $P < 0.01$, 1.000 | | | |
| F | Transformation | | None | | None | | | |
| | Habitat | 2 | 7816.6 | 1.16 | 0.44 | 0.67 | 0.06 | 0.79 |
| AC | Location(Habitat) | 12 | 6719.6 | 21.72*** | 0.66 | 4.61*** | 0.08 | 9.86*** |

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|---|---|---|---|---|---|---|---|---|
| | Residual | 60 | 309.3 | | 0.14 | | 0.12 | |
| | Total | 74 | | | | | | |
| | Cochran's test | | ns, 0.2397 | | ns, 0.1543 | | $P < 0.01$, 0.4286 | |
| | Transformation | | None | | X^0.1 | | None | |
| | Habitat | 2 | 13.52 | 1.02 | 17.67 | 2.15 | 9.76 | 1.50 |
| | Location(Habitat) | 12 | 13.23 | 98.5*** | 8.21 | 1.97* | 6.50 | 2.71** |
| | Residual | 60 | 0.13 | | 4.18 | | 2.40 | |
| | Total | 74 | | | | | | |
| | Cochran's test | | ns, 0.2174 | | ns, 0.4581 | | $P < 0.01$, 0.9806 | |
| CC | Transformation | | Sqrt(X+1) | | None | | None | |
| | Habitat | 2 | 1.84 | 1.98 | 2.09 | 2.14 | 5.49 | 0.73 |
| | Location(Habitat) | 12 | 0.93 | 6.17*** | 0.98 | 6.43*** | 5.89 | 0.01 |
| | Residual | 60 | 0.15 | | 0.15 | | 5.22 | |
| | Total | 74 | | | | | | |
| | Cochran's test | | ns, 0.1427 | | ns, 0.1923 | | $P < 0.01$, 0.9981 | |
| NCC | Transformation | | X^0.1 | | X^0.1 | | None | |

**Table 4** Two-way ANOVA comparing the numbers of faunal species (density of *T. striatus, M. neritoides* and *Patella* spp. and percent cover of *C. stellatus*) among habitats (Natural shores N, Basalt artificial structure B and Concrete artificial structure C) and locations at different intertidal levels.*** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$.

| | | | Mid-shore | | Upper-shore | |
|---|---|---|---|---|---|---|
| | | df | MS | *F* | MS | *F* |
| *T. striatus* | Habitat | 2 | 15.96 | 6.89** | 25.43 | 18.42** |
| | Location(Habitat) | 12 | 2.32 | 3.30** | 31.38 | 3.60** |
| | Residual | 60 | 0.70 | | 0.38 | |
| | Total | 74 | | | | |
| | Cochran's test | | ns, 0.1918 | | ns, 0.2141 | |
| | Transformation | | Ln(x+1) | | Ln(x+1) | |
| | Pair-wise comparisons | | | N diff. B*<br>N diff. C* | | N diff. B**<br>N diff. C*** |
| *M. neritoides* | Habitat | 2 | 2.28 | 3.84* | 0.91 | 0.79 |
| | Location(Habitat) | 12 | 0.60 | 3.57** | 1.15 | 7.11*** |
| | Residual | 60 | 0.17 | | 0.16 | |
| | Total | 74 | | | | |
| | Cochran's test | | ns, 0.1905 | | ns, 0.1377 | |
| | Transformation | | X^0.1 | | X^0.1 | |
| | Pair-wise comparisons | | | N diff. B*<br>B diff. C* | | |
| *C. stellatus* | Habitat | 2 | 17.25 | 4.66* | 0.11 | 0.16 |
| | Location(Habitat) | 12 | 3.70 | 5.39*** | 0.70 | 4.97*** |
| | Residual | 60 | 0.69 | | 0.14 | |
| | Total | 74 | | | | |
| | Cochran's test | | ns, 0.2250 | | ns, 0.1122 | |
| | Transformation | | Ln(X+1) | | X^0.1 | |
| | Pair-wise comparisons | | | N diff. B* | | |
| | | | Mid-shore | | | Low-shore |
| | | df | MS | *F* | MS | *F* |
| *Patella* spp. | Habitat | 2 | 3.07 | 0.94 | 0.05 | 0.17 |
| | Location(Habitat) | 12 | 3.28 | 4.52*** | 0.31 | 2.57* |
| | Residual | 60 | 0.73 | | 0.12 | |
| | Total | 74 | | | | |
| | Cochran's test | | ns, 0.1873 | | ns, 0.1866 | |
| | Transformation | | Ln(X+1) | | X^0.1 | |

667 **Table 5** Two-way ANOVA comparing the numbers of faunal species (density of *T.*
668 *striatus, M. neritoides* and *Patella* spp. and percent cover of *C. stellatus*) between
669 roughness (Smooth surface S, Rough surface R) and sites (Site 1, S1; Site 2, S2) at different
670 intertidal levels.*** $P < 0.001$.

| | | | Mid-shore | | Upper-shore | |
|---|---|---|---|---|---|---|
| | Source | df | MS | *F* | MS | *F* |
| *T. striatus* | Roughness | 1 | 17.02 | 18.35*** | 35.81 | 28.84*** |
| | Site | 1 | 0.84 | 0.91 | 0.27 | 0.22 |
| | Pooled Data | 17 | 0.93 | | 1.24 | |
| | Total | 19 | | | | |
| | Cochran's test | | ns, 0.5710 | | ns, 0.5099 | |
| | Transformation | | Ln(x+1) | | sqrt(x+1) | |
| *M. neritoides* | Roughness | 1 | 3.98 | 4.46 | | |
| | Site | 1 | 0.25 | 1.67 | | |
| | Roughness x Site | 1 | 0.89 | 6.05* | | |
| | | | *(S1, R>S***; S2, R=S)* | | | |
| | Residual | 16 | 0.15 | | | |
| | Total | 19 | | | | |
| | Cochran's test | | ns, 0.4034 | | | |
| | Transformation | | X^0.1 | | | |
| *Patella* spp. | Roughness | 1 | 22.05 | 0.84 | | |
| | Site | 1 | 4.05 | 0.15 | | |
| | Pooled Data | 17 | 26.40 | | | |
| | Total | 19 | | | | |
| | Cochran's test | | ns, 0.4715 | | | |
| | Transformation | | None | | | |
| *C. stellatus* | Roughness | 1 | 5313.80 | 6.69 | | |
| | Site | 1 | 405.00 | 2.71 | | |
| | Roughness x Site | 1 | 793.80 | 5.32* | | |
| | | | *(S1, R<S*; S2, R<S***)* | | | |
| | Residual | 16 | 149.20 | | | |
| | Total | 19 | | | | |
| | Cochran's test | | ns, 0.4871 | | | |
| | Transformation | | None | | | |

671